Decision-Analytic Valuation of Clinical Information Systems: Application to an Alerting System for Coronary Angiography

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BACKGROUND: Many patients who need coronary angiography fail to get it and they have decreased survival as a result. This study demonstrates the use of decision analysis to predict the survival value of an alerting system for necessary angiography.
METHODS: Data on the use of angiography and survival after myocardial infarction (MI) were taken from a published cohort study. The expected value of information (EVI) was calculated for alerts that angiography is necessary. Maximal EVI was estimated by assuming that alert advice is always followed. Sensitivity analysis relaxed that assumption. Hypothetical data were generated to demonstrate EVI analysis for narrower subcohorts.
RESULTS: A maximally effective alerting system would increase survival in this cohort by 2.2% over 1–4 years after MI. The system would therefore need to be applied to 46 people to prevent one death. Its effectiveness would decrease linearly with decreasing adherence to its advice. Given sufficiently detailed outcome and prevalence data, EVI analysis could also predict the survival value of the system's individual data elements.
CONCLUSIONS: An alerting system that ensures necessary angiography post-MI should have a survival value comparable to the value of t-PA over streptokinase. EVI analysis provides a framework for predicting the overall effectiveness of information systems and for understanding the contribution of individual features to a system's effectiveness.

INTRODUCTION

Spending on health care information systems is "ballooning" in the U.S., from \$7.5 billion in 1994 to an estimated \$11 billion for 1996.[1] The effect of these expenditures on health outcomes is unknown. Before the cost-effectiveness of a technology is assessed, however, methods should be in place for understanding its health effects.[2]

Decision analysis provides a method for calculating the expected value of information (EVI) when faced with a decision under uncertainty.[3] This method has been used in technology assessment for diagnostic tests[5] and in planning clinical trials.[4] Analysis of EVI should be especially useful in understanding the value of systems that consist mainly of information.

Information systems are increasingly important in the implementation of clinical practice guidelines.[6] Guidelines should preferably be based on evidence,[7] but high quality evidence is often lacking for important clinical decisions.[6] The RAND/UCLA consensus method provides an alternative foundation for guidelines by rigorously identifying areas of expert agreement.[8] Table 1 shows a small sample of the RAND expert ratings of indications for coronary angiography.[9] A recent study has demonstrated the validity of these ratings by showing that patients who did not receive necessary angiography had

Table 1. Excerpt from the RAND ratings of necessity for coronary angiography.[9] A procedure is necessary if it would be improper care not to provide it and if has a "reasonable chance" of producing a significant benefit. Each combination of patient features forms an "indication." The necessity of coronary angiography for each indication was rated on a scale of 1 to 9 by nine expert panelists. The "rating bar" in the center of each cell below shows the possible ratings. The numbers above the bar show how many panelists chose each rating for the given indication. The numbers below the bar show the **median rating** and the mean absolute deviation from the median. Median ratings less than 7 indicate that the procedure's necessity is uncertain.

Chapter 7 PATIENTS WITHIN 12 WEEKS OF AN ACUTE MI, WHO HAVE BEEN DISCHARGED FROM INITIAL HOSPITALIZATION	Q WAVE INFARCT WITH CHF	Q WAVE INFARCT WITHOUT CHF	NON-Q WAVE INFARCT
Under 75 years old, Post-MI angina occurs with moderate exertion (Class I/II), Positive exercise stress test, No stress imaging study, and:			
a. No or less than maximal medical management	2 3 3 1 1 2 3 4 5 6 7 8 9 (**6.0**, 0.9)	2 4 1 1 1 1 2 3 4 5 6 7 8 9 (**6.0**, 0.9)	1 4 2 2 1 2 3 4 5 6 7 8 9 (**6.0**, 1.0)
b. Maximal medical management	3 3 2 1 1 2 3 4 5 6 7 8 9 (**7.0**, 0.8)	3 2 3 1 1 2 3 4 5 6 7 8 9 (**7.0**, 0.9)	2 2 2 3 1 2 3 4 5 6 7 8 9 (**8.0**, 1.0)

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Table 2. Distribution of mortality in a cohort study[10] that followed patients at least one year and as long as four years post-MI. The necessity of angiography was assessed for each patient in the study using the RAND criteria. [9] Relative risk estimates were adjusted for age, sex, race, comorbidity, CHF, prior MIs, and medications. Values in *italics* are calculated from data reported.

Necessity of coronary angiography	Actual use of coronary angiography	Risk of death, angiogram vs. no angiogram	Number of patients observed	Number of patients who died	Probability of death in 1-4 yrs with angiogram	Probability of death in 1-4 yrs without angiogram
Necessary	77.5%	0.29	440	68	*9.96%*	*34.4%*
Not Necessary	*33.2%*	0.55	669	141	*13.6%*	*24.8%*

substantially higher mortality.[10] An information system that supplies necessity alerts to clinical decision makers could therefore improve patient survival. This study demonstrates the use of decision analysis to find the EVI for advice on the necessity of angiography under a variety of assumptions.

METHODS

Data Extraction

The data shown in Table 2 were extracted from a published cohort study that followed patients from 7 hospitals in a large health maintenance organization (HMO) during 1–4 years after an MI.[10]

Decision Analysis

Decision analysis[11] was carried out using Microsoft Excel, v. 7.0 (Redmond, Wash.). Decision trees were displayed graphically in Excel by selectively darkening cell borders. (See Figure 1.) In a decision tree, paths from left to right through the tree represent each potential outcome of the initial decision, which is represented by a branch point marked with a square. Branch points marked with circles are chance nodes, with the expected probability of following each branch shown below the line. Values at the end-branches show the survival probability for patients reaching the given outcome. Values in italics show the expected survival at each node, found by averaging the downstream survival values, weighted by the chance node probabilities. The expected value of information (EVI) is the utility difference between informed and uninformed subtrees. Since this study considers only survival in assessing utility, the EVI is equivalent to a mortality absolute risk reduction (ARR). The number-needed-to-treat (NNT) to prevent one death is the reciprocal of the ARR.[12]

Assumptions and Sensitivity Analysis

Values for the variables used in decision analyses are shown in Table 3. 95% confidence intervals were estimated for proportions using the normal approximation of the binomial distribution. To estimate the maximal value of an alerting system the base analysis assumed that alerts are always heeded. A sensitivity analysis[11] then calculated the EVI across lower levels of compliance with the alerts.

Table 3. Values used in decision analyses.

Variable	Estimate (95% CI)	Comments
a. Data for the whole post-MI cohort		
Probability of coronary angio. being necessary post-MI	0.397 (0.37, 0.43)	440/1109, from reference[10]
Probability of having an angiogram when necessary	0.775 (0.75, 0.80)	from reference[10]
Probability of having angio. when not necessary	0.332 (0.36, 0.30)	from reference[10]
Probability of survival when necessary angiogram is done	0.9003 (0.87, 0.93)	from reference[10]
Probability of survival when necessary angio. is not done	0.656 (0.61, 0.70)	from reference[10]
Probability of survival when not necessary angio. is done	0.864 (0.84, 0.89)	from reference[10]
Probability of survival when not necessary angiogram is not done	0.753 (0.72, 0.78)	from reference[10]
Probability of having an angiogram when necessary given a guideline system	1	Base assumption of maximal effectiveness
b. Hypothetical data for the subcohort with Table 1 indications: MI in last 12 weeks, age under 75, moderate angina, positive ETT		
Prevalence of maximal medical management	0.397	Same as parent cohort (for demonstration purposes only)
Probability of having an angiogram if on maximal medical management	0.775	
Probability of having an angio. if not on maximal medical management	0.332	Same assumption
Probability of survival if on maximal med. management & angiogram is done	0.9003	Same assumption
Probability of survival if on maximal med. management & angiogram is not done	0.656	Same assumption
Probability of angiography when the clinician is missing important information	0.554	Average of current rates for necessary and not.

Expected Value of Information for a Subcohort

The value of an alerting system could be expected to vary for different subcohorts within the post-MI population. If the examination of subcohorts could be carried to the limiting extreme, EVI analysis might find the expected value of obtaining and using an individual data element (*i.e.* patient variable). To explore this potential, outcome data was synthesized for the hypothetical subcohort of patients who fit the indications in Table 1. Since this data is arbitrary, it is simply assumed that survival and angiogram probabilities are the same in this subcohort as in the parent cohort for the indications rated necessary (≥7) and for those rated not necessary, as shown in Table 3, part B. When a clinician is missing information important to their decision about angiography (independent of RAND criteria) it is assumed that angiography is performed at an intermediate rate, as shown in the last row of Table 3.

RESULTS

Expected Survival Benefit of a Guideline System

The decision tree shown in Figure 1 calculates the improvement in survival that could be expected from an alerting system for necessary coronary angiography in the post-MI cohort reported by Selby, et al.[10] The tree starts with a decision between implementing an information system and continuing current practice. The first chance node in each arm represents the probability in this cohort that angiography is in fact necessary (0.397). In the *alerting system* arm, clinicians are informed of the necessity of angiography, and under base-case assumptions they would always perform angiography when so informed. When angiography is not flagged as necessary this analysis assumes that clinicians continue their current practice since angiography remains "appropriate" in many of these patients (and a benefit from angiography is in fact apparent in the outcome data). In the *current practice* arm clinicians continue to judge necessity based on the usual sources of information, and they continue to perform angiography in only 77.5% of those who would be judged necessary by the RAND criteria. Averaging the survival values back along the decision tree results in an expected survival of 0.834 for the informed arm and 0.812 for the current practice arm. The maximal expected value of information (EVI_{max}) for necessity advice is the survival difference between these arms, an absolute risk reduction (ARR) of 2.2% in the chance of dying during the 1 to 4 year follow-up period for this cohort.

Sensitivity Analysis for Survival Benefit

The EVI_{max} analysis assumes that the system is completely effective in bringing about angiography when necessary. The sensitivity analysis in Figure 2 shows the linear decline in the EVI as this assumption is relaxed toward the necessary angiography rate of 77.5%, where the system would have no value over current practice. If an alerting system simply achieved the 89% necessary angiography rate of the best hospital in the Selby study, the system's ARR would be 1.1% (NNT=89.7%). Figure 2 also shows 95% confidence limits for the sensitivity analysis, estimated by using the worst-case and best-case 95% confidence limits for each parameter from Table 3. The resulting confidence range for EVI_{max} is 1.3% to 3.4%.

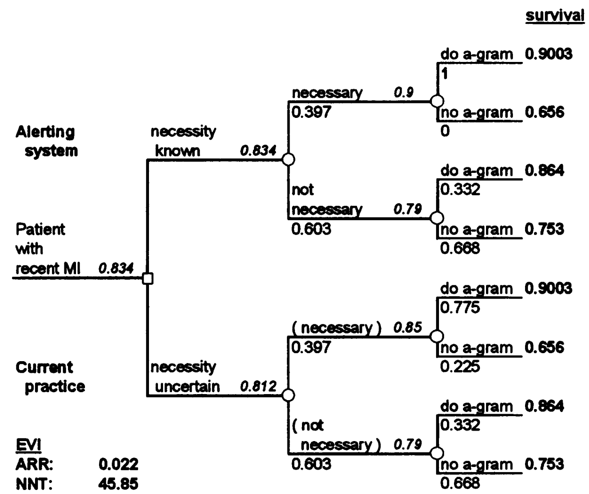

Figure 1. Decision tree showing the expected value of information (EVI) from an alerting system for necessary angiography. The EVI is expressed both as an absolute morality risk reduction (ARR) and as the number needed to treat (NNT) to prevent one death.

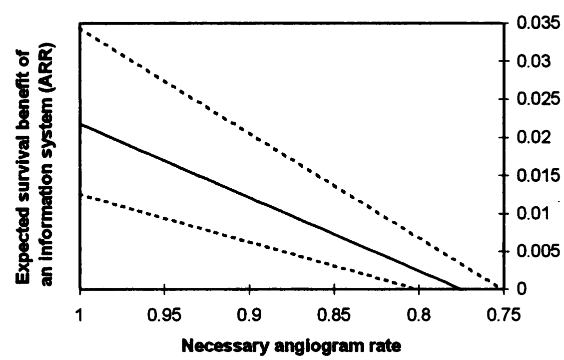

Figure 2. Sensitivity analysis showing the decline in value of an alerting system with decreasing adherence to its advice. Dashed lines represent upper and lower bounds of the expected value using 95% confidence interval data.

Expected Value of Individual Data Elements

Some units of patient data would contribute more than others to the guideline system's ability to create value. A patient's hair color, for example, would have no value for determining the necessity of angiography. The value of most data elements used by the RAND criteria, however, would depend on the context of what's already known about the patient. EVI analysis could theoretically be applied to ever-narrower subcohorts of patients as long as enough prevalence and outcome data are available to be statistically meaningful. When a group is narrow enough, data from a single variable would determine actions while the remaining variables would have no value. Such a subcohort is represented in Table 1, where the necessity of angiography is completely determined by the patient's being on maximal medications. EVI analysis would show no value within this subcohort for a system that acquired data about CHF or Q-waves compared with one that did not. A system that did not acquire medication data, on the other hand, would fail to provide an alert for patients on maximal management. Assuming for the sake of demonstration, as shown in Table 3b, that probabilities are the same in this subcohort as in the parent cohort, the decision tree would be identical to Figure 1 except that the upper arm would be labeled "acquire medication status" and the lower "medication status unknown." The EVI for this data element in this narrow subcohort would be ARR = 2.2%. The EVI for a data element in a broader cohort could then be found by averaging its EVI across all mutually exclusive subcohorts, weighted by the number of patients in each subcohort.

EVI can be predicted for other systems as long as the effect of information on outcomes can be estimated. Figure 3 demonstrates the EVI of medication data for patients being evaluated for angiography, under the assumptions in Table 3b. The clinician with access to medication data proceeds with decision making under current practice conditions. Without this information, the clinician might be less certain about performing angiography. If the probability of angiography is then the average of the current rates when necessary and not necessary, the ARR for having on-line medication data would be 0.0069.

DISCUSSION

Health information systems can be valued on the same scales used to assess any health care technology. Even in planning stages the expected value of an information system can be predicted if the effect of information on outcomes can be accurately estimated. Based on data from a large HMO cohort,[10] this analysis finds that an angiography alerting system could increase survival after myocardial infarction by as much as 2.2% over current practice. Under the more conservative assumption that such a system would only bring angiography practice up to the level of the best hospital, the resulting 1.1% increase in survival at 1–4 years would still compare favorably with other health interventions, such as the 1.1% increase in 1-year survival found for patients treated with t-PA rather than streptokinase in acute MI.[13]

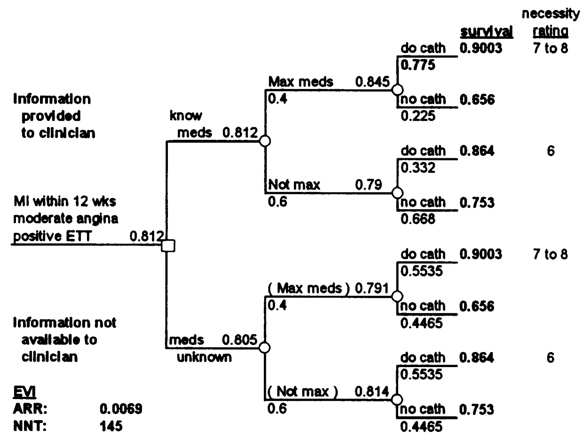

Figure 3. Decision tree demonstrating EVI analysis for one feature of a non-guideline information system.

This study further shows that with sufficiently detailed outcome data EVI analysis could predict the value of individual data elements in a subpopulation. Values for these subgroups could be averaged to find the overall value of a data element to a guideline system. Subgroup values might also be used to drive sequential data collection.[14] Thus the EVI method can evaluate information systems both at the overall level and at the level of individual system features. It may also facilitate a linkage between expert opinion and outcome- or evidence-based decision making.

A prior study has demonstrated the use of decision tables to value individual data elements used by RAND expert panels.[15] That approach counted for each data element the number of pairs of indications for which the data element produced no change in actions. This count was then used to prioritize the use of data elements in guideline development. This approach would resemble a simplified EVI analysis in which the value of a data element is binary and subgroups are weighted equally for averaging across the population. Whether the full EVI approach is worth the added complexity awaits further study.

Limitations of the analyses presented here should be considered. Data was taken from one observational cohort study. Because the study was not randomized, part of the difference in survival between patients who did and did not receive angiography could be due to unmeasured factors. The study did, however, measure and adjust for several known mortality risk factors (see methods), so any bias due to imbalances in these factors was eliminated. Nonetheless, to the extent that unmeasured factors account for survival differences the effectiveness of a guideline system would be reduced. Results based on this study might also be inapplicable to other populations, such as patients with fee-for-service health insurance.

This paper demonstrates EVI analysis using only survival benefits. Future work will consider additional outcomes. Most important will be costs, not only of system implementation but also of changes in the care delivered. Though costs and health benefits should eventually be integrated in a cost-effectiveness ratio,[16] it is appropriate to focus on the effectiveness of a new technology before taking on a detailed assessment of costs.[2] This paper assumes that angiography is reasonably cost-effective for patients judged necessary. Health related quality of life (HRQL) outcomes should also be considered. If HRQL data were available for the current cohort they might be combined with survival data to estimate benefits as quality-adjusted life years. More difficult to model will be the external benefits of information systems to society, such having more outcomes data available and improving marketplace competition.

In conclusion, finding the expected value of information supplied by an information system should eventually provide a rational basis for allocating investments in medical informatics.

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